Theme 2: Modeling, Data Assimilation and Advanced Computing

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WRF-Chem

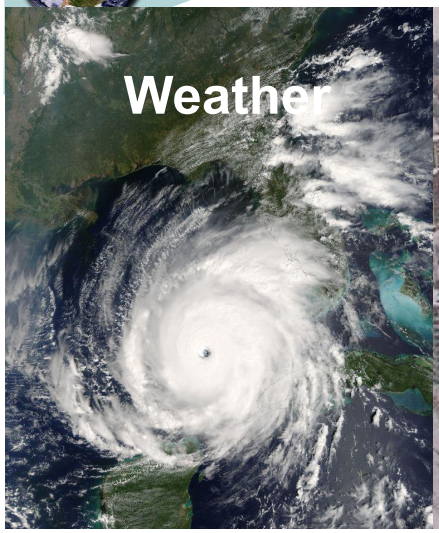
Outline

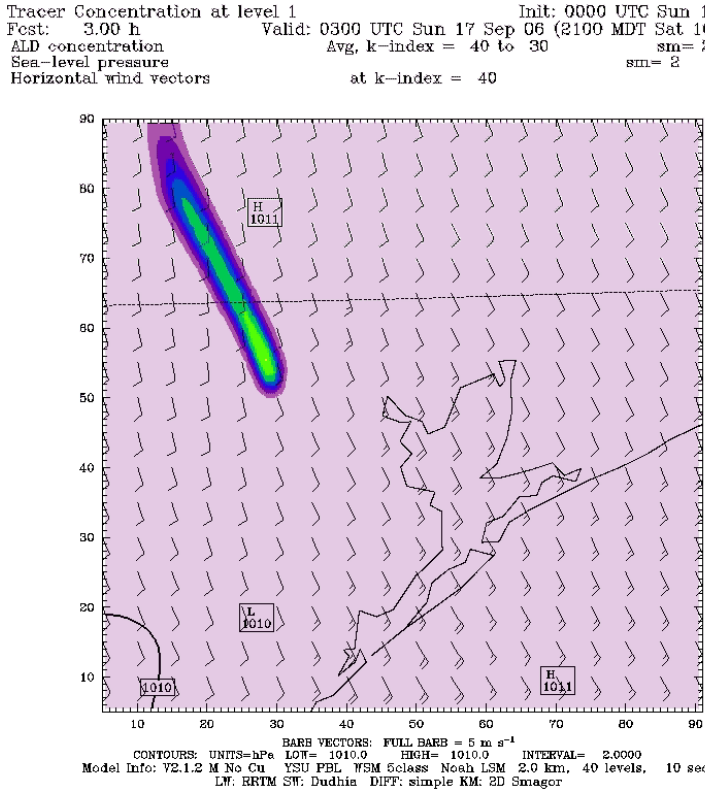
- Background on WRF-Chem
- Focus on Aerosol - the weather/air quality, and climate link
- Example of volcanic ash-fall prediction
- Example of a study to show the impact of smoke from wildfires on weather
- Chemical data assimilation using NCEP's Grid Point Statistical Interpolation (GSI) system and WRF-Chem
- Ongoing and future work

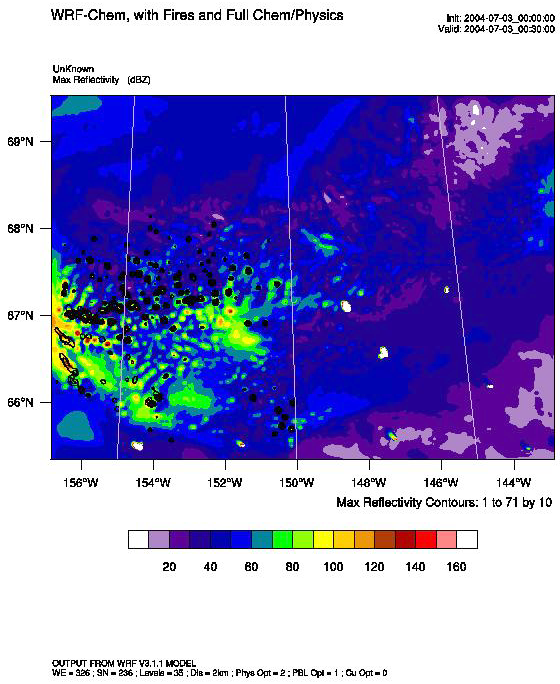
WRF-Chem: widely used nationally and internationally, development led by ESRL

- Main developer groups: ESRL (GSD, CSD, PSD), Pacific Northwest Laboratory (PNNL), NCAR
- Other contributors: NASA, University of Chile, Center for Weather Forecast and Climate studies (CPTEC in Brazil), Max Planck Institute (MPI Mainz),….
- ESRL develops, collects new developments, provides tutorials, documentation and user support for a large number of users nationally and internationally (also includes Air Force Weather Agency (AFWA), also evaluates new modules (CSD)
- WRF-Chem is a state-of-the-art modeling system with chemistry and aerosol modules that range from very simple to very complex, and can be used from global to local scales

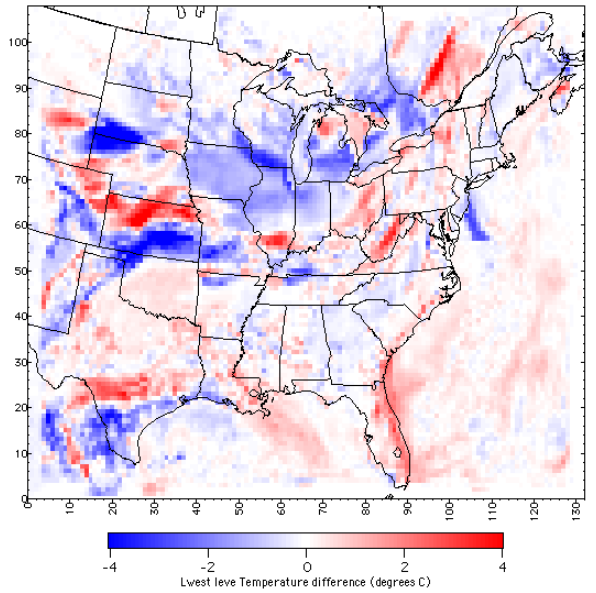
Current Possible Applications







Example of T difference caused by semi-direct effect



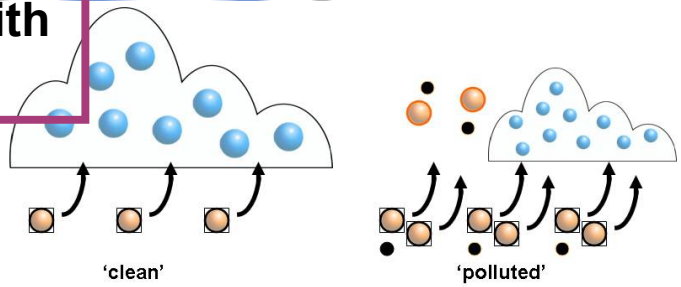
Aerosols may be the most important link between weather, air quality, and global climate change.

Available Aerosols Modules

1. PM advection, transport, emissions and deposition only
2. Bulk approach (from GOddard Chemistry Aerosol Radiation and Transport Model, GOCART)
   - Run in real time at ESRL for Rapid Refresh, and High-resolution Rapid Refresh (RR-Chem and HRRR-Chem)
   - Numerically very efficient
3. Modal approach
   - Used at ESRL for air quality forecasts on smaller experimental domains and for field experiments
   - Used also for research applications
4. Sectional approach
   - Research applications

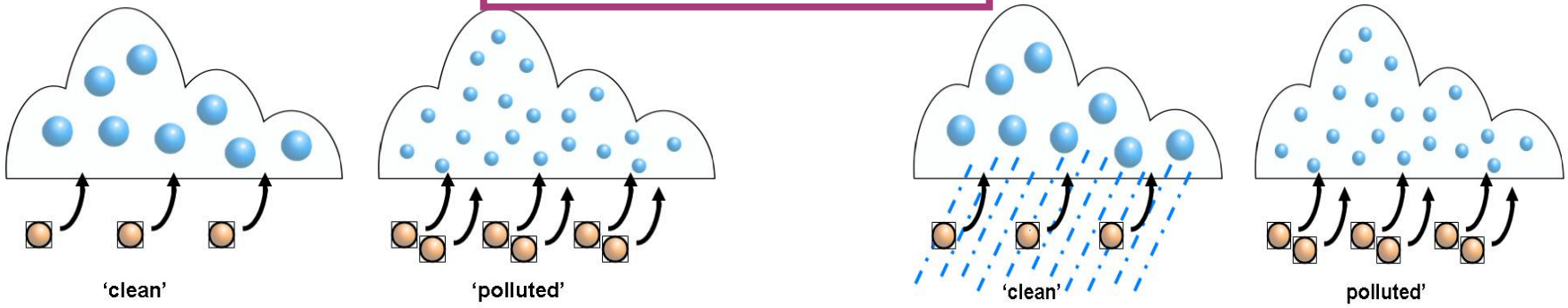
Aerosol Effects Included in WRF/Chem

Direct Interaction with radiation



Direct and semi-direct effects are caused through the direct interaction of aerosols with radiation

Direct Interaction with microphysics

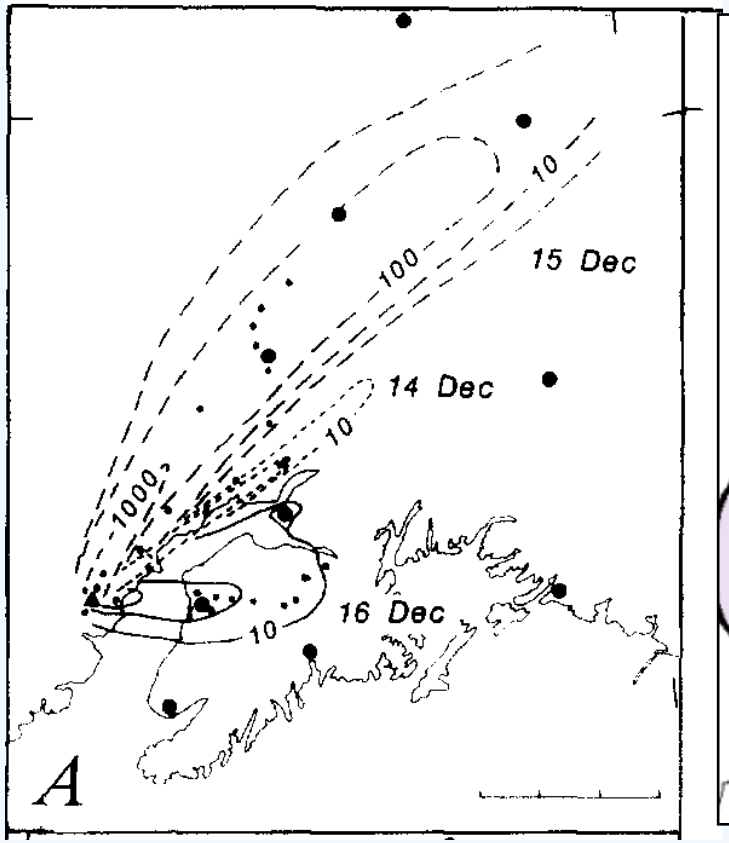


Indirect effects are caused because of the interaction of aerosols with cloud microphysics (through Cloud Condensation Nuclei)

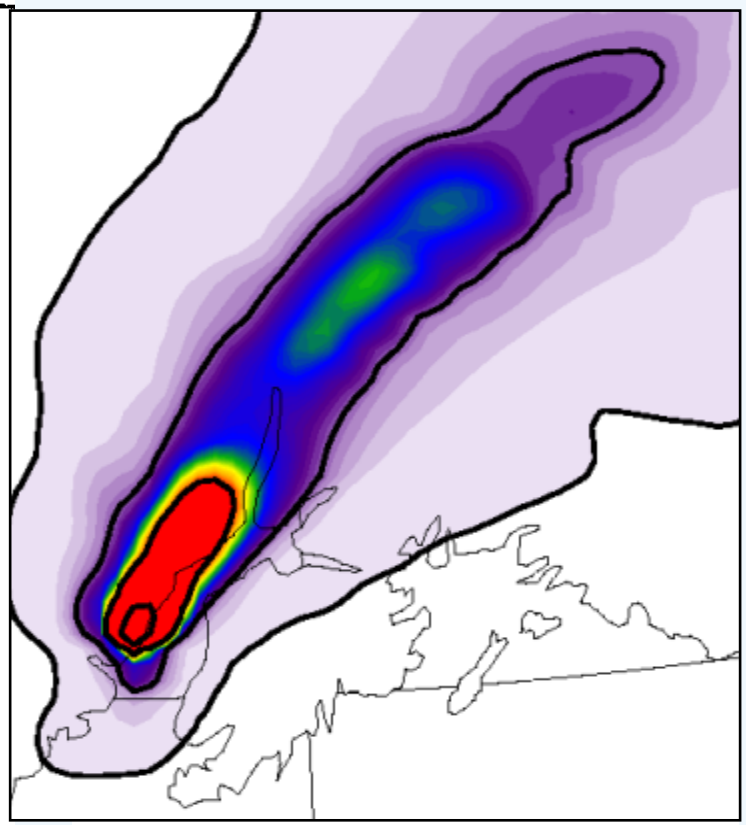
Important sources for aerosols: Fires and Volcanoes

Both are a threat for health and aviation

Tephra-fall deposits (g/m^2), Redoubt Volcano south-central Alaska, explosive 43-minute eruption 1989 December 15, 1989



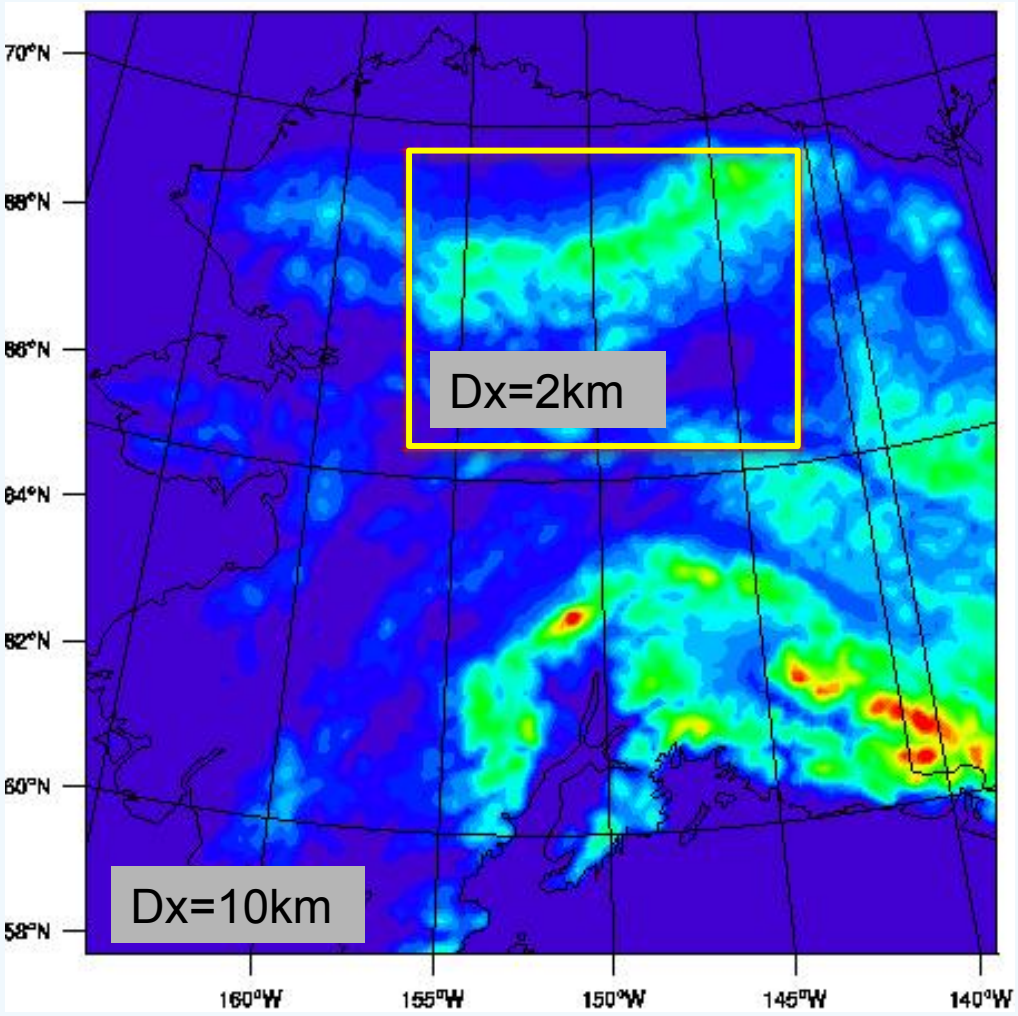
Observed



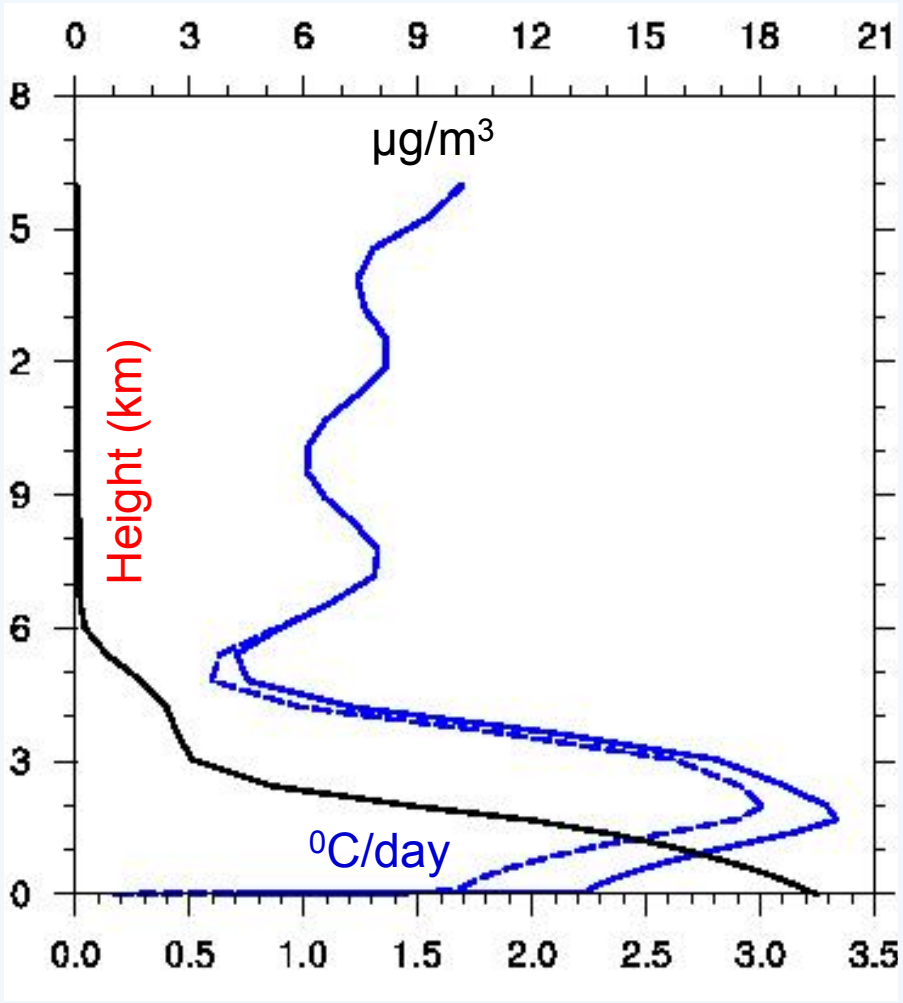
Predicted by WRF-Chem, using *RR-Chem setup*

WRF-Chem simulation on effects of fires on weather

1) 10-day spin up
2) 2-day simulations
   - with and without fires
   - GOCART as well as complex chemistry setup
   - Initial and boundary conditions from (1)
3) Fires initialized using WF-ABBA, MODIS, as well as aerial and ground observations



Domain 2, dx=2km, Box averages (180km^2) over fairly dry and very smoky areas at July 3, 21Z



Short wave radiation tendency with fires

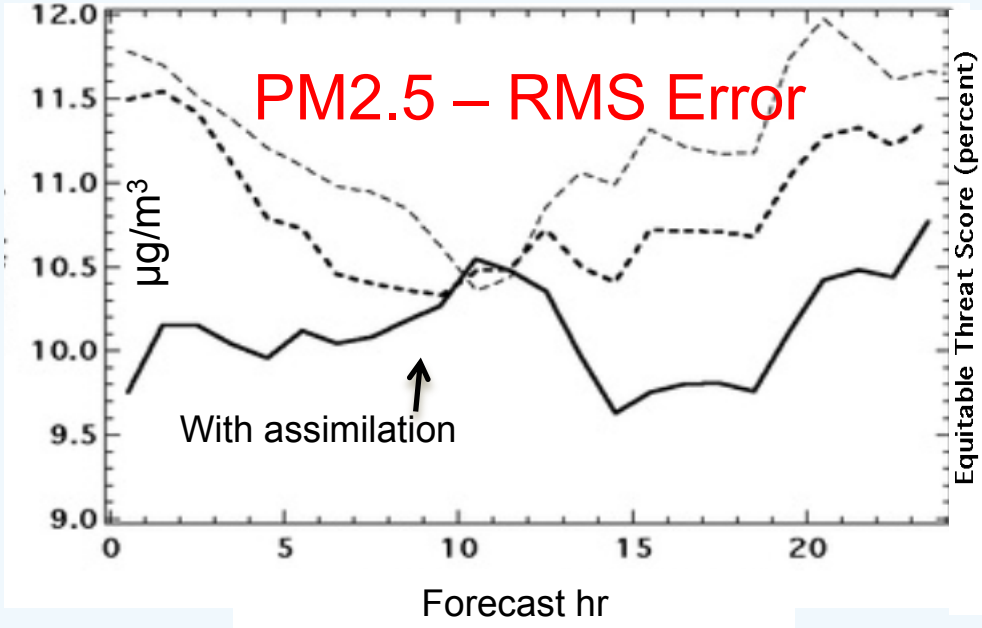
Short wave radiation tendency without fires

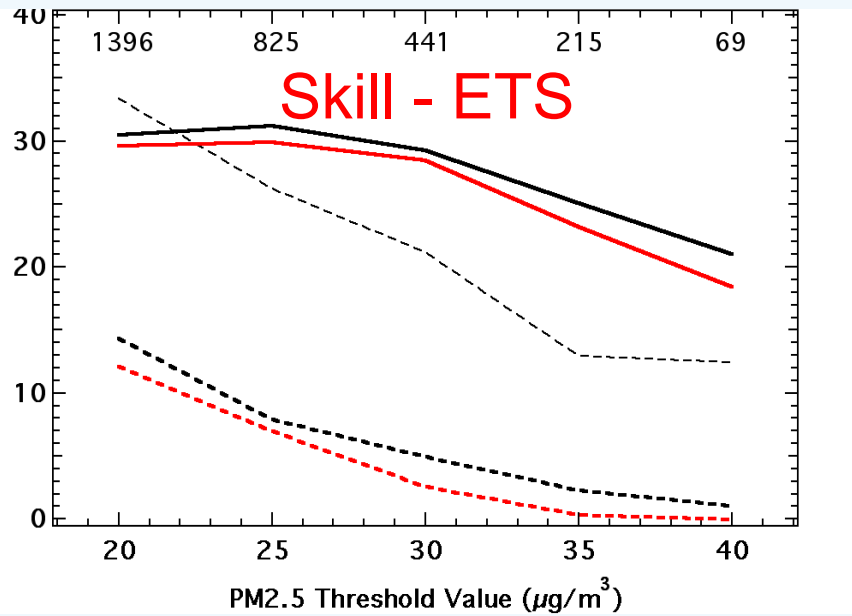
PM2.5 concentration (ug/m^3)

Chemical data assimilation: ARW/WRF-Chem and GSI

2 months worth of WRF/Chem runs:

1. New England 2004 to estimate background error covariances and length scales
2. Houston 2006 for evaluation





- Evaluation using AIRNOW surface monitors
- 50 runs, 24-hr forecasts
- 27-km resolution over central and eastern USA

RADM/SORGAM (No Assimilation)
RADM/SORGAM (With Assimilation)
RACM/GOCART (No Assimilation)
RACM/GOCART (With Assimilation)
previous day (persistence)

Chemical data assimilation: ARW-WRF/Chem and GSI

Ongoing project:

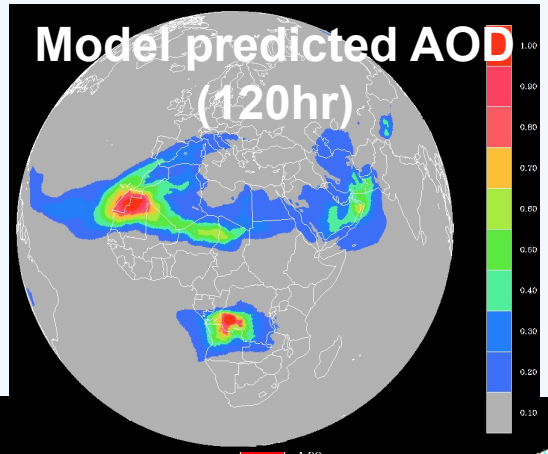
- Develop and deliver operational system for air quality and weather forecasting and assimilation of weather and aerosol data for Air Force Weather Agency (Cooperative project ESRL/NCAR)
- Assimilation of AOD and surface PM data, using WRF-Chem and GSI
- Rapid Refresh framework (dx=13km for North American Grid)
- Also to be used for High Resolution Rapid Refresh (HRRR, dx=3km over continental US)
- Determine effect of chemical data assimilation on meteorological data assimilation

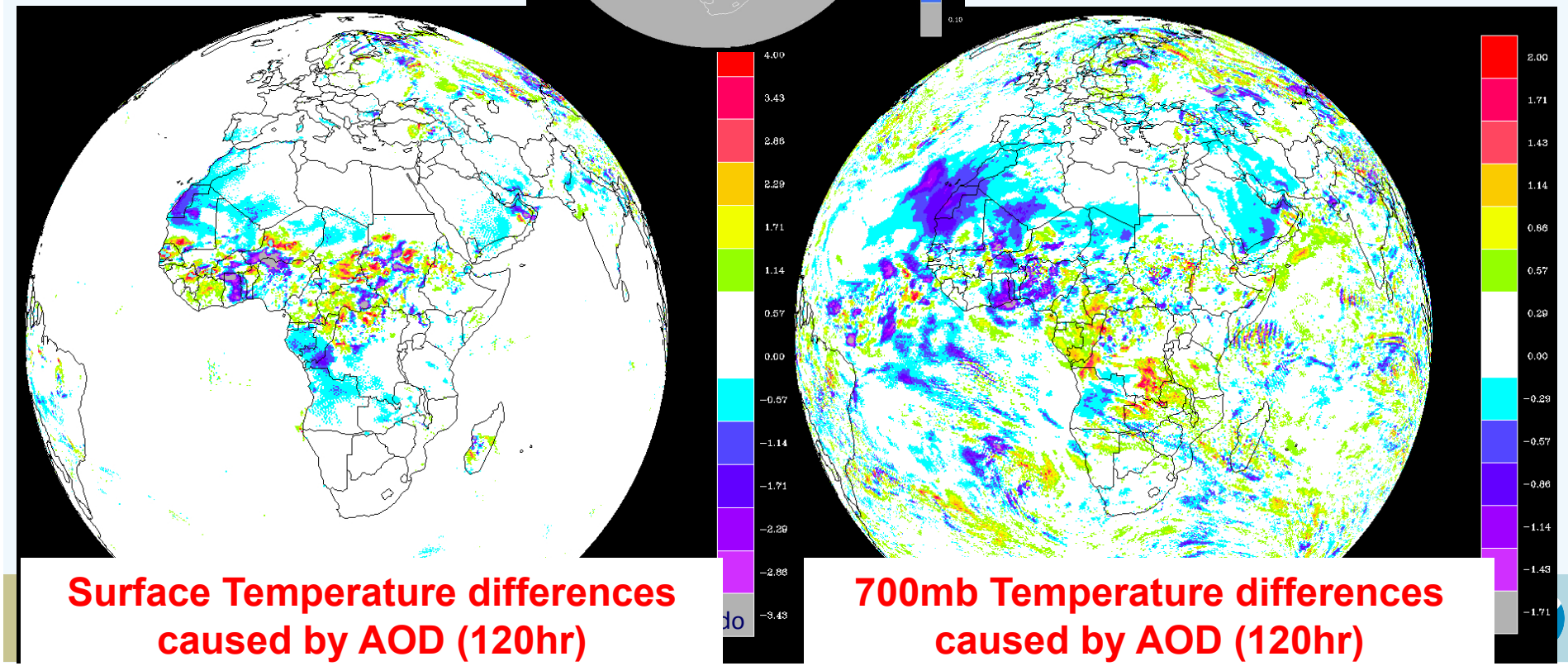
Currently calculating background error statistics from RR-Chem

Future line-up for WRF/Chem, only current ESRL work

- Aerosol interaction with radiation and microphysics
- Chemical data assimilation
  - 4dvar, collaboration with U of Iowa, U of Colorado, and ESRL/GSD
  - 3dvar and EnsKF
  - Implementation of ESRL's chemical data assimilation approach at NCEP (System will be transferred to NOAA/ARL)
- Provide AFWA with operational forecast system (possible impact on visibility as well as weather forecasts)
- More choices for "interactive" parameterizations, shallow convection (ESRL/GSD), NMM-WRF/Chem will become available
- Implementation of all chemistry modules into FIM

FIM-Chem: The effect of online chemistry for weather forecasts





Surface Temperature differences caused by AOD (120hr)

700mb Temperature differences caused by AOD (120hr)

Example of what is coming: LES simulations of Aerosol Effects on Cloud Morphology via Drizzle (research in CSD)

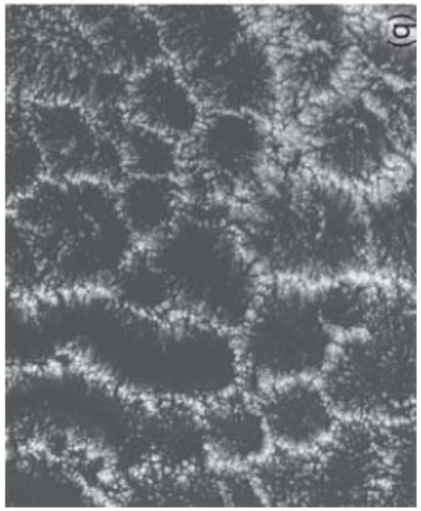
Albedo

Closed-cell
Albedo ~ 0.6
(non-precipitating)

→ **high aerosol**

Onset of ***drizzle*** *results in transition to open-cell convection*

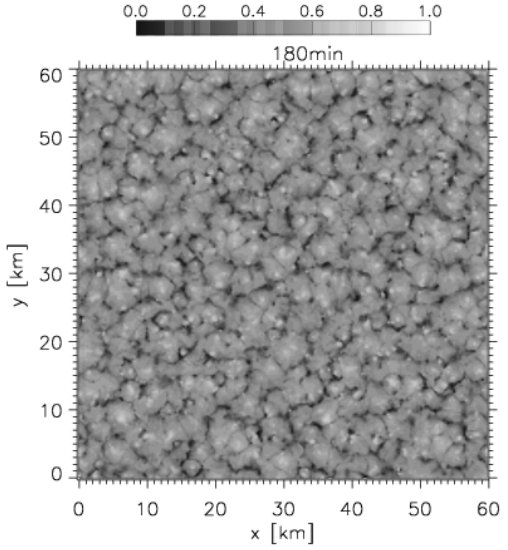
WRF Model
+ 2-moment microphysics;
60-km domain;
Dx = Dy = 300 m
Dz = 30 m

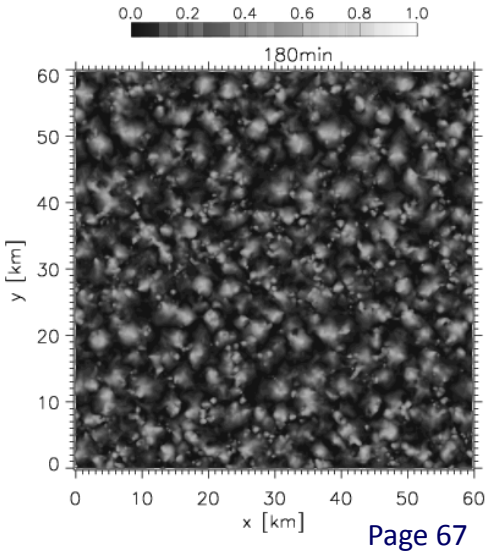


Open-cell
Albedo ~ 0.2
(precipitating)

→ **low aerosol**

Albedo





Garay et al. 2004, MISR

Wang and Feingold, 2009